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Exhaust Emission Tests of Four Heavy Duty Gasoline Spark-Ignited Engines

Southwest Research Inst, San Antonio, Tex

Prepared for

National Air Pollution Control Administration, Ann Arbor, Mich Div of Motor Vehicle Research and Development

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by
Clifford D. Tyree
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FINAL REPORT

Prepared for
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John M. Clark, Jr., Director
Department of Automotive Research

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I. INTRODUCTION

Gasoline, spark-ignited, engines manufactured on or after January 1, 1970, for use in heavy duty vehicles must comply with exhaust emission standards established by the Department of Health, Education and Welfare. The June 4, 1968, Federal Register, Volume 33, Number 108[1] describes the standards and measurement procedures for the heavy duty engine exhaust emissions for hydrocarbons and carbon monoxide. The emissions by this method shall not exceed:

(1) hydrocarbons - 275 ppm

(2) carbon monoxide - 1.5 percent by volume

The test to determine these concentration levels consists of constant speed (2000 rpm ± 100) engine operations while varying the engine intake manifold vacuum (load) during the test sequence. The exhaust gases generated during the test sequence are sampled continually and specific component concentrations obtained via nondispersive infrared (NDIR) analyzers. The basic exhaust emission test is designed to provide single values for hydrocarbon and carbon monoxide on an engine dynamometer simulating a truck driving pattern in a metropolitan area.

This is the final engineering report by Southwest Research Institute for the National Air Pollution Control Administration covering the confirmation tests on four heavy duty gasoline engines. These confirmation tests were conducted in accordance with Subpart I of Reference 1. The National Air Pollution Control Administration (NAPCA) Project Officer was Mr. Robert Walter. The Project Director at Southwest Research Institute was Mr. Karl Springer, who was assisted by Mr. Clifford Tyree.

II. EQUIPMENT AND INSTRUMENTATION

The object of these confirmation tests was to obtain single composite values for hydrocarbons and carbon monoxide from a continuous sample of exhaust gases during the 9-mode heavy duty truck cycle as set forth in Subpart I of Reference 1.

The engine dynamometer used was a Universal Dynamatic motoring dynamometer with a Tate-Emory control system for constant speed operation. The dynamometer is capable of 300 hp absorbing and 50 hp motoring. The dynamometer and engine instrument control panel are shown in Figure 1. Note also the large 0-30-inch vacuum gage for monitoring engine manifold vacuum.

The continuous sampling and analysis system shown in the background in Figure 2 meets the requirements of the Federal Register[1] and was used on the subject program. The system includes a regulated exhaust-gas flow rate through water condensate traps to four rapid and continuous NDIR analyzers. The analysis system consists of a carbon monoxide (CO) analyzer--0 to 11 percent, a carbon dioxide (CO_2) analyzer--0 to 15 percent, and two hydrocarbon (HC) analyzers--0 to 1000 ppm and 0 to 10,000 ppm HC as normal (n) hexane. The continuous analyzer readout is accomplished via two dual-pen strip chart recorders.

After the installation of each engine on the dynamometer, Figures 3-6, a brief period of operation, less than one hour, was conducted to make sure the engine was operating satisfactorily. A practice run-through of the Federal procedure was then made to familiarize the dynamometer operator with engine response and other operating characteristics. The full 20-minute procedure, as shown in Table 1, was followed in the practice runs.

TABLE 1. DESCRIPTION OF 9-MODE HEAVY DUTY GASOLINE ENGINE TEST SCHEDULE

Sequence No.	Mode	Manifold Vacuum	Time in Mode, sec	Cumulative Time, sec	Weighting Factors
1	Idle		70	70	0.036
2	Cruise	16" Hg	23	93	0.089
3	PTA	10" Hg	44	137	0.257
4	Cruise	16" Hg	23	160	0.089
5	PTD	19" Hg	17	177	0.047
6	Cruise	16" Hg	23	200	0.089
7	FI	3" Hg	34	234	0.283
8	Cruise	16" Hg	23	257	0.089
9	CT		43	300	0.021

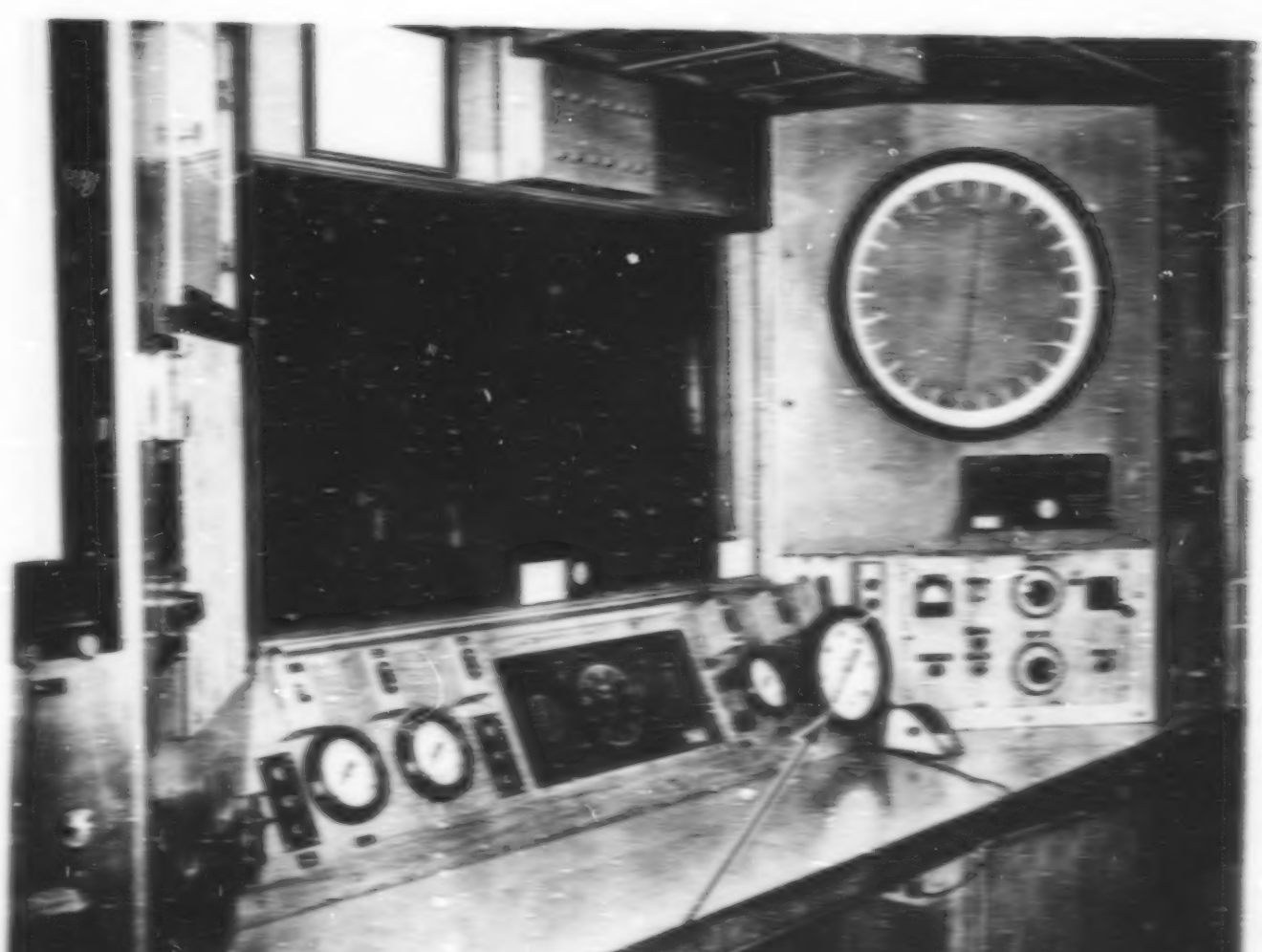


FIGURE 1. ENGINE DYNAMOMETER CONTROL PANEL

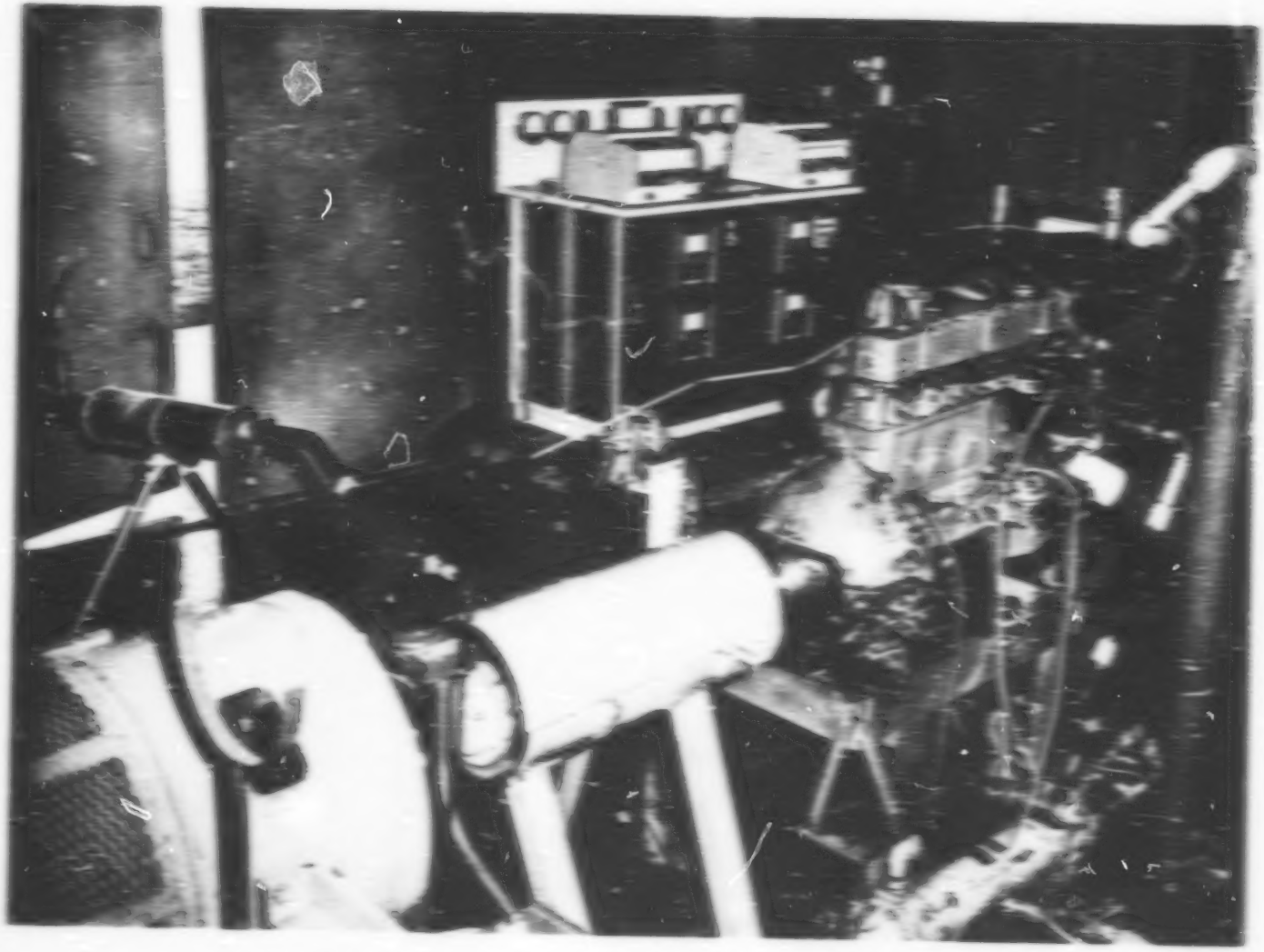


FIGURE 2. CONTINUOUS NONDISPERSIVE INFRARED CART USED FOR EXHAUST SAMPLING AND ANALYSIS

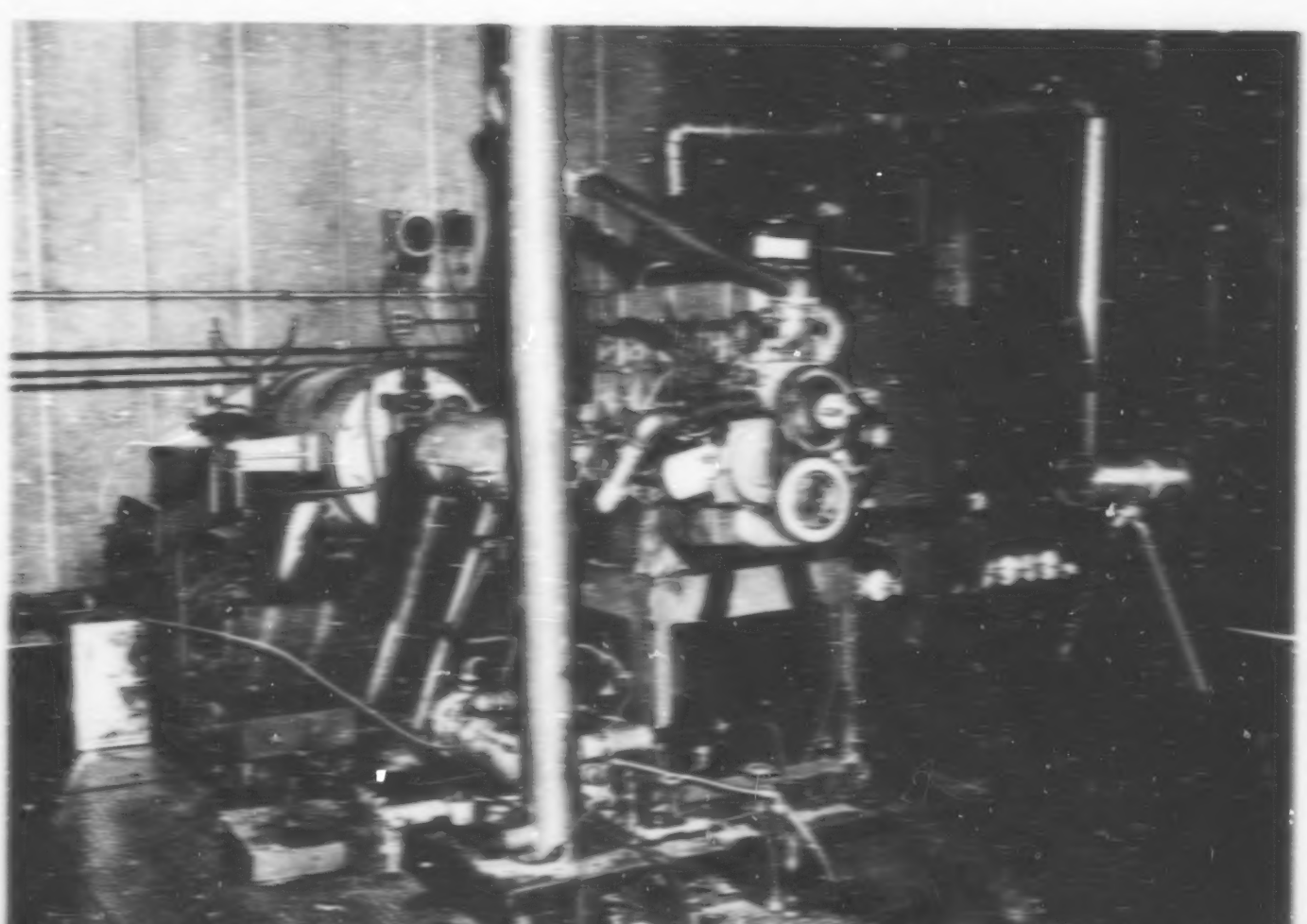


FIGURE 3. CHEVROLET 292 CID, I-6, GASOLINE ENGINE PREPARED FOR FEDERAL EXHAUST EMISSIONS TEST

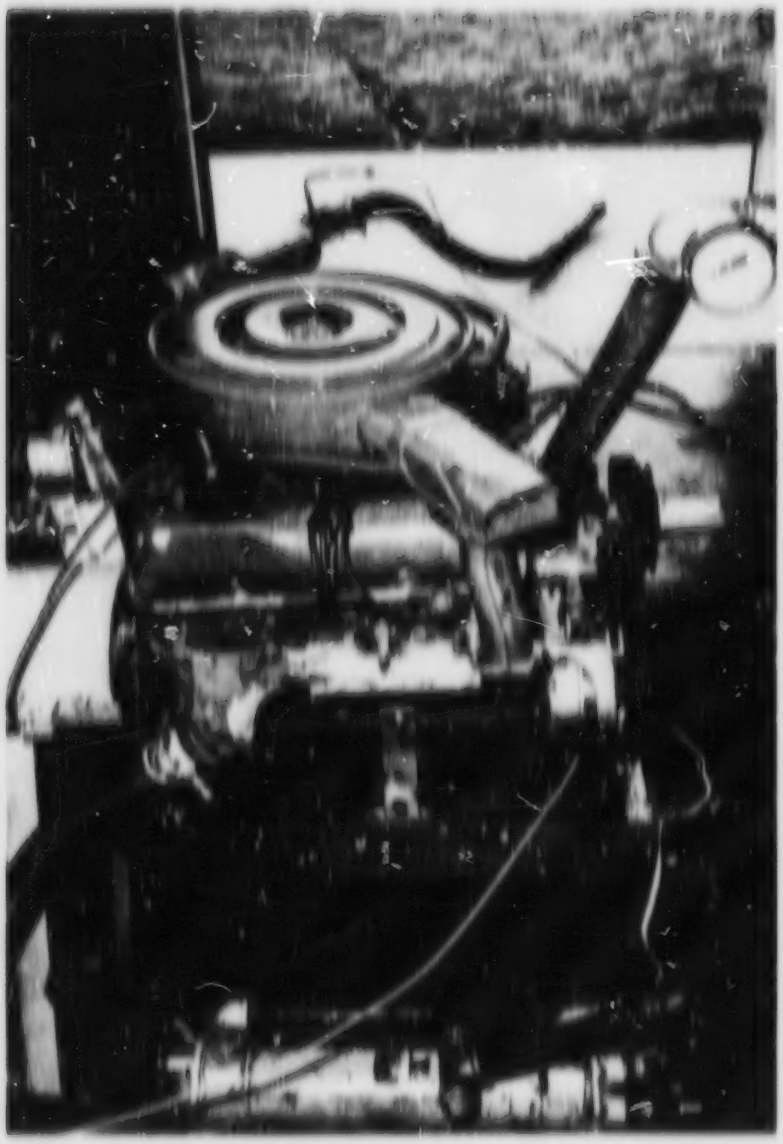


FIGURE 4. FORD 360 CID, V-8, GASOLINE ENGINE PREPARED FOR FEDERAL EXHAUST EMISSION TEST

FIGURE 5. CHRYSLER 318 CID, V-8, GASOLINE ENGINE PREPARED FOR FEDERAL EXHAUST EMISSION TEST

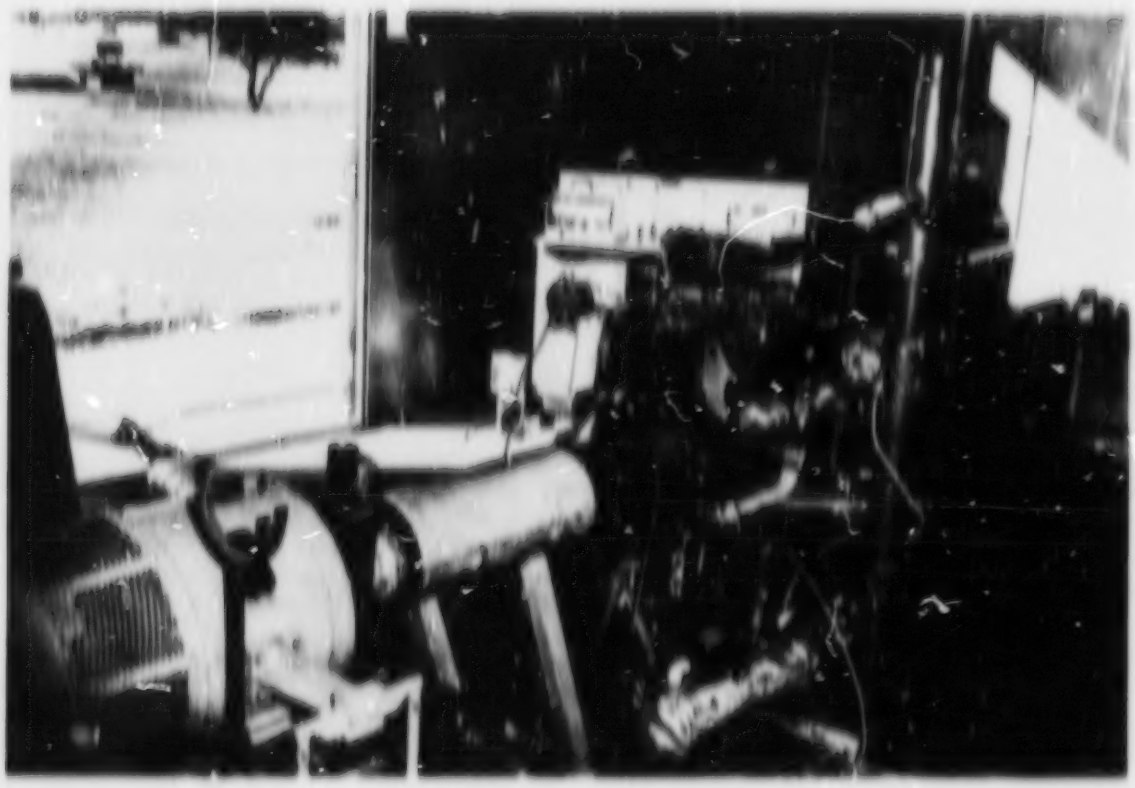


FIGURE 6. INTERNATIONAL HARVESTER 393 CID, V-8, GASOLINE ENGINE PREPARED FOR FEDERAL EXHAUST EMISSION TEST

The continuous sampler monitored and recorded the concentration levels during each run. The traces obtained from these practice runs were used to observe the repeatability of the test.

For the purposes of the run for record, the alternative procedure, allowed in para. 85.103 of Reference 1, was used. This permits an idle mode at the beginning and end of each test, thus eliminating the need to change engine speed between cycles. After completion of the run for record, observed by the NAPCA Project Officer, the traces were checked for any discrepancies such as length of time in each mode, engine misfires, etc. The traces were then hand-read and expressed in terms of observed concentration. These raw values were then recorded on computer input sheets, key punched, and data reduced (corrected and weighted) by the SwRI-CDC 6600 digital computer.

On Monday, January 26, 1970, the Division of Motor Vehicle Pollution Control gas simulator was used by Mr. Paul Jones and Mr. Mats Macocha of NAPCA to check the response and calibration of the continuous sampler used for this project. The tolerance allowed for each instrument was ±2-percent full scale reading. Shown in Table 2 below are the results of the calibration check.

TABLE 2. CALIBRATION RESULTS OF SwRI'S CONTINUOUS SAMPLER

Instrument and Range	Allowed Deviation	SwRI Deviation
Low Hydrocarbons, 0-1000 ppm	±20 ppm	+ 14.33 ppm
Carbon Monoxide, 0-11%	±0.22%	− 0.09%
Carbon Dioxide, 0-15%	±0.30%	− 0.11%

Note: The DMVPC simulator was not equipped to check high range hydrocarbons.

Although the gas simulator was not made available for a calibration check at the beginning of the program, there were no changes made during the four tests that would affect the validity of the calibration check. Fuel used for all tests was as specified in the Federal Register for emission tests from gasoline fueled spark-ignited engines.

III. RESULTS AND DISCUSSION

Presented here are the final results taken from the appropriate traces for each of the four engines. The engines were tested and data are presented in the order in which the engines were received at SwRI. Engine description is given in Table 3.

TABLE 3. DESCRIPTION OF HEAVY DUTY GASOLINE ENGINES TESTED

Manufacturer	Displacement	Cyl	Engine No.	Carb. No.	Dist. No.
Chevrolet	292	I-6	F1025RF 19887-A	7029022	1116-467-F005197-2
Ford	360	V-8	X8T2-360-4-45T	XF191000 (X9T23901136)	C7UF-12127-6H17
International Harvester	392	V-8	4110	379483-C19	383149-C91-882
Chrysler	318	V-8	ED-318-T-558-00	25337/7	2875-128-218 E179

Tables 4-7 are reproductions of the computer printout for each of the four engines tested. The as-measured concentrations are listed for hydrocarbons, carbon monoxide and carbon dioxide followed by the dilution factor used to determine the adjusted values of hydrocarbons and CO. Using the weighting factors from Table 1, each mode's contribution is computed in order to arrive at the cycle composite. The four composite cycle runs are then combined as follows:

$$\text{Four-Cycle Composite} = \frac{(\text{Cycles 1 + 2})}{2} 0.35 + \frac{(\text{Cycles 3 + 4})}{2} 0.65$$

The 292 CID Chevrolet was tested without incident. The results shown in Table 4 were slightly higher in hydrocarbons and lower in carbon monoxide relative to the results provided by the manufacturer to SwRI.

During the first run for record of the 360 CID Ford, a misfire occurred during the 3-inch vacuum mode of the second cycle. It was necessary to abort this run and determine the cause of misfire. (The timing and idle rpm of each engine were checked during the preliminary run-in to insure that

TABLE 4. EXHAUST EMISSIONS FROM 292 CID CHEVROLET I-6 HEAVY DUTY GASOLINE ENGINE

MODE	CONCENTRATION (% BY VOLUME)			DILUTION FACTOR	ADJUSTED		WEIGHTING FACTOR	WEIGHTED	
	HC	CO	CO2		HC	CO		HC	CO
1 IDLE	66	.000	11.400	1.221	81	.077	.086	0.902	.085
2 1600G	100	.400	12.800	1.178	118	.471	.069	10.485	.042
3 1000G	90	0.000	11.600	1.244	82	0.000	.057	10.988	0.000
4 1600G	80	.600	12.000	1.192	95	.691	.069	8.203	.062
5 1900G	105	.200	12.100	1.154	121	.305	.047	8.696	.034
6 1500G	65	.200	12.100	1.156	75	.300	.069	8.744	.072
7 RATED	70	2.100	11.500	1.168	82	2.410	.283	28.791	.664
8 1600G	70	.500	12.200	1.156	81	.579	.069	7.210	.052
9 IDLE	3561	1.400	8.100	1.169	3904	1.636	.086	81.088	.014
SLP	CYCLE COMPOSITE							166.278	1.017
1 IDLE	66	.000	11.400	1.221	81	.077	.086	0.902	.085
2 1600G	96	.600	12.200	1.151	99	.691	.069	8.819	.061
3 1000G	65	.100	12.000	1.108	72	.100	.057	13.860	.031
4 1600G	75	.300	12.200	1.148	86	.004	.069	7.883	.073
5 1900G	71	.000	12.200	1.140	81	.018	.047	5.817	.043
6 1600G	96	.600	12.200	1.143	84	.919	.069	7.636	.081
7 RATED	90	1.800	11.600	1.158	98	2.078	.283	10.143	.060
8 1600G	70	.000	12.200	1.144	80	.919	.069	7.197	.063
9 IDLE	3178	1.803	8.200	1.171	3720	1.787	.086	78.117	.017
SLP	CYCLE COMPOSITE							166.279	1.030
1 IDLE	60	.000	11.900	1.178	67	.060	.086	1.490	.084
2 1600G	95	.000	12.100	1.140	108	1.041	.069	9.600	.092
3 1000G	60	.200	11.900	1.201	70	.200	.057	20.068	.062
4 1600G	75	.600	12.100	1.171	88	.668	.069	7.817	.062
5 1900G	134	.200	12.100	1.151	154	.806	.047	7.197	.038
6 1600G	91	.500	12.100	1.165	106	.588	.069	9.616	.092
7 RATED	85	2.100	11.700	1.179	96	2.371	.283	27.161	.671
8 1600G	80	.500	12.000	1.175	94	.588	.069	8.369	.052
9 C.T.	3099	1.600	8.200	1.180	3631	1.884	.086	76.054	.039
SLP	CYCLE COMPOSITE							167.881	1.077
1 IDLE	60	.000	11.900	1.178	67	.060	.086	1.490	.084
2 1600G	91	.500	12.200	1.156	105	.870	.069	9.550	.091
3 1000G	65	.200	12.000	1.101	72	.200	.057	19.903	.061
4 1600G	75	.600	12.200	1.153	86	.692	.069	7.893	.062
5 1900G	134	.200	12.100	1.140	153	.806	.047	8.103	.043
6 1600G	82	.700	12.300	1.138	93	.797	.069	8.307	.071
7 RATED	60	1.800	12.300	1.159	69	1.109	.283	12.780	.300
8 1600G	60	.600	12.200	1.163	70	.605	.069	8.012	.041
9 C.T.	3080	1.300	8.400	1.172	3608	1.523	.086	76.774	.060
SLP	CYCLE COMPOSITE							150.116	.719

FELR CYCLE COMPOSITE
HC = 157.577
CO = .941

DILUTION FACTOR = (14.5/(CO2+(5.9/0.6)*CO+0.002))

they were set to manufacturers specification.) The timing was rechecked at idle and found to be properly adjusted. The spark plugs were then removed for inspection. It was during the removal of the spark plugs that one spark plug wire was found to be broken near the crimp-on adapter at the spark plug end. The item was replaced using the same plug wire and with a new set of spark plugs. After replacing the spark plugs and the crimp-on adapter, the engine showed no signs of misfire at the 3-inch vacuum level. Another run-for-record was scheduled for the next day. This run was made with no further incidents and the values recorded in Table 5. These results indicate a slightly higher level of both carbon monoxide and hydrocarbons relative to the results provided to SwRI by the engine manufacturer.

The International Harvester 393 CID engine made its run for record without incident. The results shown in Table 6 represent a slight increase in carbon monoxide but a very substantial decrease of hydrocarbons relative to the results provided to SwRI by the manufacturer. No explanation can be given as to why this significant reduction in hydrocarbons occurred.

The Chrysler 318 CID was the last engine tested. From the very beginning of the practice dynamometer operation, a slight misfire occurred. After checking the compression and replacing the spark plugs with new ones, the engine was still running rough. The Sun 1120 engine analyzer was used to determine if the misfire could be detected under load. Even under load, no single cylinder indicated improper firing relative to the others. The points were checked, but were not "dressed," and appeared normal. Because of the nature of the test being conducted, the amount and extent of "tune-up" allowed was limited. It was decided by the Project Officer to proceed with the run for record. The results for this engine are shown in Table 6. Both hydrocarbons and carbon monoxide were higher relative to the results provided to SwRI by the manufacturer. Because the results reported in Table 7 for carbon monoxide were above the Federal standards, the decision was made by NAPCA to verify the calibration of the continuous sampler used. The results of this calibration check were shown in Table 2, previously discussed.

After the run for record was completed for each engine, the engine would remain on the dynamometer until the NAPCA Project Officer reviewed the exhaust emission traces and considered preliminary hand calculated emissions results. The engine was then stored until the final computer results were available for review. Then, with the consent and approval of the NAPCA Project Officer, the engines were returned to the respective manufacturers.

Shown in Appendix A are four tables, A1 to A4, which contain the computer values of the calibration curves for each of the four instruments used on the continuous sampler. Shown in Appendix B, and provided only with copy no. 1 of this final report, are the original charts for each of the

TABLE 5. EXHAUST EMISSIONS FROM 360 CID FORD V-8 HEAVY DUTY GASOLINE ENGINE

MODE	CONCENTRATION AS MEASURED HC	CO	CO2	DILUTION FACTOR	ADJUSTED HC	CO	WEIGHTING FACTOR	WEIGHTED HC	CO
1 IDLE	408	2,800	12,700	.997	407	2,792	.086	14,847	.401
2 1500G	145	.500	14,000	1.006	146	.503	.049	10,980	.049
3 [illegible]00	97	.500	13,900	1.005	98	.503	.097	28,560	.081
4 1500G	120	.500	14,100	1.001	120	.501	.049	10,695	.049
5 1900G	105	.300	13,700	1.038	109	.312	.047	9,198	.015
6 1500G	122	.500	13,900	1.015	124	.508	.049	11,026	.049
7 30HG	169	2,500	13,600	.998	169	2,495	.283	46,767	.706
8 1500G	146	.500	14,000	1.001	146	.501	.049	10,971	.049
9 CT	4535	2,900	7,300	1.062	4816	3,081	.091	131,182	.066
SUM	CYCLE COMPOSITE							280,988	1,466
1 IDLE	408	2,800	12,700	.997	407	2,792	.086	14,847	.401
2 1500G	145	.500	14,000	1.010	146	.505	.049	10,980	.049
3 1000G	96	.300	13,900	1.078	97	.324	.097	24,941	.081
4 1500G	120	.500	14,000	1.008	121	.504	.049	11,658	.049
5 1900G	105	.300	13,700	1.031	108	.309	.047	9,491	.015
6 1500G	137	.500	14,000	1.007	138	.504	.049	12,270	.049
7 30HG	169	2,200	13,900	.980	170	2,156	.283	60,470	.610
8 1500G	142	.500	14,000	1.003	142	.502	.049	10,979	.049
9 CT	4487	2,800	7,400	1.063	4768	2,978	.091	100,178	.062
SUM	CYCLE COMPOSITE							248,287	1,050
1 IDLE	408	4,300	10,900	1.078	439	4,632	.086	15,787	.166
2 1500G	140	.700	14,000	1.006	140	.704	.049	12,450	.032
3 1000G	77	.300	13,800	1.048	81	.314	.097	20,743	.081
4 1500G	108	.500	14,000	1.010	109	.505	.049	9,701	.049
5 1900G	98	.400	13,800	1.029	101	.411	.047	4,899	.019
6 1500G	132	.600	14,100	.997	132	.598	.049	11,716	.059
7 30HG	160	.900	14,000	.998	160	.894	.283	59,349	.253
8 1500G	138	.700	14,000	1.001	138	.700	.049	11,978	.069
9 CT	4454	2,800	7,600	1.050	4676	2,940	.091	95,005	.062
SUM	CYCLE COMPOSITE							253,787	.804
1 IDLE	408	5,400	10,900	1.078	439	4,858	.086	15,787	.136
2 1500G	157	.600	14,000	1.002	157	.601	.049	14,002	.054
3 1000G	95	.300	13,700	1.030	98	.312	.097	25,373	.080
4 1500G	135	.500	14,000	1.008	136	.504	.049	11,658	.049
5 1900G	137	.300	13,900	1.021	140	.306	.047	8,970	.014
6 1500G	150	.600	13,700	1.025	154	.615	.049	12,747	.059
7 30HG	175	2,400	13,600	.988	172	2,371	.283	48,857	.666
8 1500G	130	.700	14,100	.994	129	.696	.049	11,498	.068
9 CT	4434	3,100	7,200	1.064	4684	3,269	.091	102,945	.069
SUM	CYCLE COMPOSITE							248,784	1,210

FOUR CYCLE COMPOSITE
HC = 249.202
CO = 1.041

DILUTION FACTOR = (14.5/(CO2+(.5CO+1.5HC)))

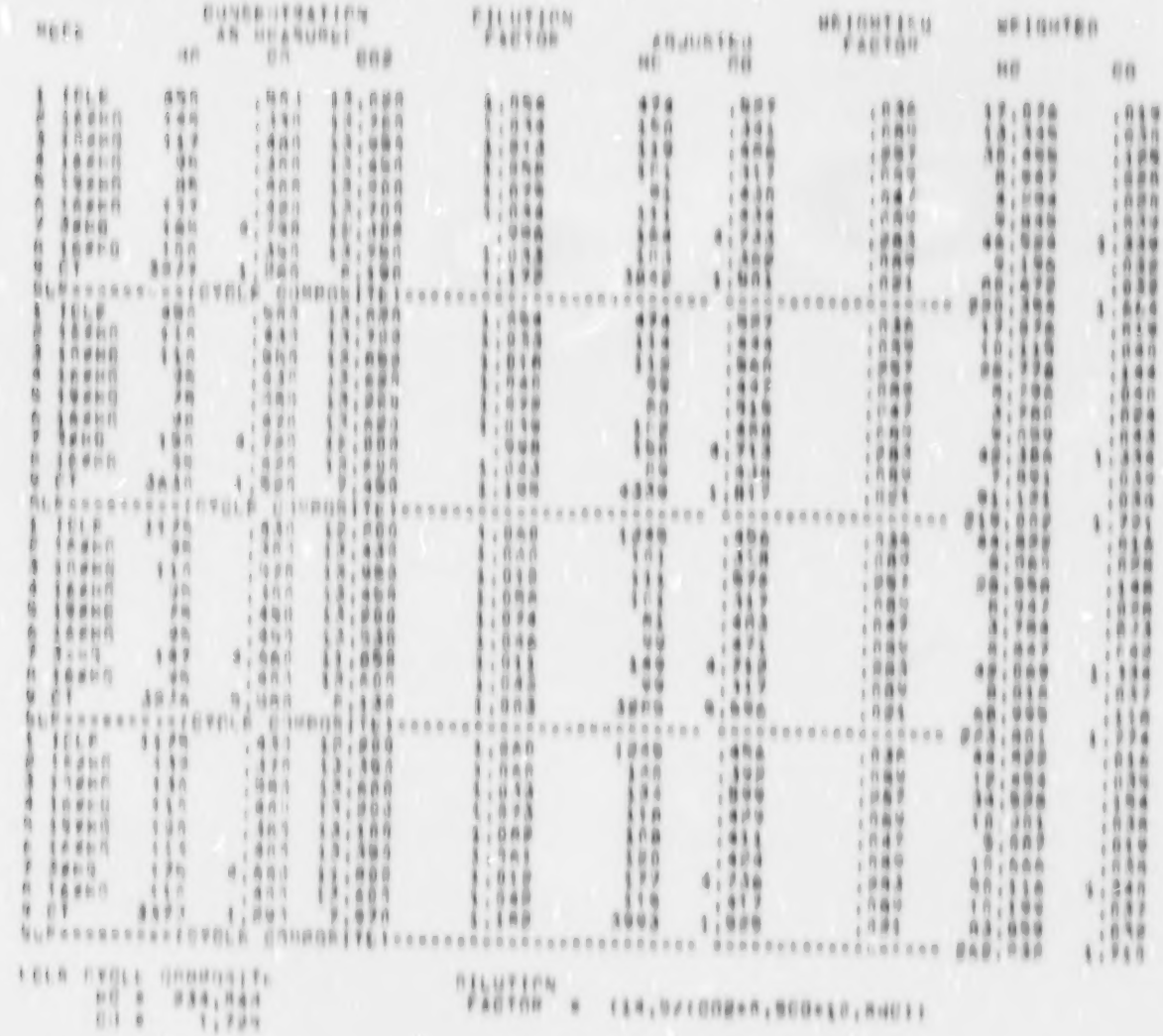
TABLE 6. EXHAUST EMISSIONS FROM 398 CID INTERNATIONAL HARVESTER V-8 HEAVY DUTY GASOLINE ENGINE

MODE	CONCENTRATION AS MEASURED HC	CO	CO2	DILUTION FACTOR	ADJUSTED HC	CO	WEIGHTING FACTOR	WEIGHTED HC	CO
1 IDLE	337	2,100	13,000	.970	326	2,040	.036	11.736	.074
2 1500RPM	69	300	14,200	1.026	62	305	.080	5.550	.027
3 1700RPM	66	300	14,000	1.050	62	300	.297	18.157	.108
4 1800RPM	65	300	14,200	1.059	60	303	.080	5.144	.027
5 1900RPM	80	1,100	14,300	.978	66	1,070	.047	3.098	.050
6 1800RPM	68	300	14,400	.996	66	300	.080	5.313	.027
7 2000RPM	70	1,000	14,000	.990	70	990	.283	19.787	.280
8 1800RPM	60	300	14,100	1.010	60	305	.080	5.154	.027
9 CY	3886	3,300	7,000	1.072	3956	3,036	.091	60.050	.674
SUM	(CYCLE COMPOSITE)							141.654	.995
1 IDLE	337	2,100	13,000	.970	326	2,040	.036	11.736	.074
2 1500RPM	65	300	14,000	.982	64	303	.080	5.070	.025
3 1700RPM	66	300	13,700	1.034	69	317	.297	17.077	.103
4 1800RPM	60	300	14,000	.988	59	296	.080	5.022	.026
5 1900RPM	95	1,000	14,300	.954	91	1,026	.047	4.260	.072
6 1800RPM	67	300	14,500	.986	66	295	.080	5.073	.026
7 2000RPM	106	1,200	14,000	.970	103	1,167	.283	29.091	.330
8 1800RPM	70	300	14,000	.981	70	305	.080	5.418	.024
9 CY	3868	3,700	7,400	1.076	4201	3,984	.091	69.266	.364
SUM	(CYCLE COMPOSITE)							176.720	.813
1 IDLE	325	2,100	13,000	.960	310	2,022	.036	11.167	.073
2 1500RPM	66	300	14,200	.962	63	287	.080	5.044	.024
3 1700RPM	62	300	13,900	1.010	64	309	.297	21.441	.131
4 1800RPM	70	300	14,200	.966	68	287	.080	5.441	.024
5 1900RPM	100	1,200	14,000	.993	99	1,190	.047	4.681	.056
6 1800RPM	65	300	14,500	.985	64	296	.080	5.098	.024
7 2000RPM	95	900	14,400	.976	92	873	.283	25.944	.247
8 1800RPM	65	300	14,700	.973	63	290	.080	4.781	.024
9 CY	3948	3,700	8,000	1.060	3746	3,504	.091	78.966	.882
SUM	(CYCLE COMPOSITE)							164.080	.742
1 IDLE	325	2,170	13,000	.960	310	2,072	.036	11.167	.107
2 1500RPM	67	300	14,500	.965	64	286	.080	5.073	.024
3 1700RPM	60	300	13,700	1.031	62	309	.297	18.607	.159
4 1800RPM	60	300	14,000	.986	59	296	.080	4.388	.024
5 1900RPM	85	1,300	14,400	.988	77	1,178	.047	3.602	.090
6 1800RPM	65	300	14,400	.993	65	298	.080	5.178	.027
7 2000RPM	80	1,100	14,200	.981	78	1,081	.283	22.201	.378
8 1800RPM	60	300	14,500	.986	61	304	.080	4.563	.026
9 CY	4009	3,700	7,400	1.068	4276	3,943	.091	69.787	.883
SUM	(CYCLE COMPOSITE)							161.457	.791

FOUR CYCLE COMPOSITE
HC = 161.169
CO = .760

DILUTION FACTOR = (14.9/(CO2+(.9CO+15.8HC)))

TABLE 7. EXHAUST EMISSIONS FROM 318 CID CHRYSLER V-8 HEAVY DUTY GASOLINE ENGINE



four engines. One chart contains low and high range hydrocarbons; the high range hydrocarbons are shown in red ink and the low range in green. Carbon monoxide and carbon dioxide traces are shown on the other chart; carbon monoxide is in red and carbon dioxide in green.

IV. SUMMARY

Four heavy duty gasoline spark-ignited engines have been tested under applicable Federal regulations and test procedures. This report describes the test methods, equipment, and instrumentation and presents the composite emission values obtained. The raw and corrected/weighted values are presented for each of the four engines tested; a 192 CID Chevrolet, a 392 CID International Harvester, a 360 CID Ford, and a 318 CID Chrysler. A calibration and response check of SwRI's continuous sampler was made by officials from NAPCA at the end of the test series. The results indicated satisfactory agreement between SwRI and NAPCA laboratories. Original data (strip chart records) for the four engine tests are included in Copy No. 1 of this report. In most cases, the results of these tests confirmed those reported by the manufacturer to Southwest Research Institute at the time the engines were shipped.

APPENDIX A

CALIBRATION DATA FOR SwRI CONTINUOUS NONDISPERSIVE INFRARED EXHAUST EMISSION ANALYZERS

TABLE A.1. LOW RANGE HYDROCARBON (0-1000 ppm) CALIBRATION PRINTOUT

Beckman IR Analyser Calibration Readout for
Low Range N-Hexane (0-1000 ppm)
Recorder Deflection vs ppm Hexane Concentration

Model No. 315 Amplifier No. 1001125 Detector No. 1530A

0-25		26-50		51-75		76-100	
Meter	ppm C_6	Meter	ppm C_6	Meter	ppm C_6	Meter	ppm C_6
0	0						
1	8.9	26	227.8	51	460.4	76	722.1
2	17.7	27	236.6	52	470.1	77	733.2
3	26.6	28	245.5	53	480.0	78	744.4
4	35.4	29	254.5	54	490.0	79	755.6
5	44.1	30	263.4	55	500.0	80	766.9
6	52.9	31	272.4	56	510.1	81	778.2
7	61.6	32	281.4	57	520.2	82	789.5
8	70.4	33	290.3	58	530.3	83	800.9
9	79.1	34	299.6	59	540.6	84	812.4
10	87.8	35	308.7	60	550.8	85	823.8
11	96.5	36	317.9	61	561.4	86	835.3
12	105.2	37	327.0	62	571.5	87	846.9
13	113.9	38	336.3	63	582.0	88	858.5
14	122.6	39	345.6	64	592.4	89	870.1
15	131.3	40	354.9	65	603.0	90	881.8
16	140.0	41	364.2	66	613.5	91	893.5
17	148.7	42	373.6	67	624.2	92	905.2
18	157.5	43	383.1	68	634.9	93	916.9
19	166.2	44	392.5	69	645.6	94	928.7
20	174.9	45	402.1	70	656.4	95	940.5
21	183.7	46	411.7	71	667.2	96	952.4
22	192.5	47	421.3	72	678.1	97	964.3
23	201.3	48	430.9	73	689.0	98	976.1
24	210.1	49	440.7	74	700.0	99	988.1
25	218.9	50	450.4	75	711.0	100	1000.0

TABLE A.2. HIGH RANGE HYDROCARBONS (0-10,000 ppm)
CALIBRATION PRINTOUT

Beckman iR Analyzer Calibration Readout for
High Range N-Hexane (0-10,000 ppm)
Recorder Deflection vs ppm Hexane Concentration

Model No. 315 Amplifier No. 1001169 Detector No. 1800A

0-25		26-50		51-75		76-100	
Meter	ppm C_6	Meter	ppm C_6	Meter	ppm C_6	Meter	ppm C_6
0	0						
1	83.3	26	2158.3	51	4409.0	76	7036.9
2	166.5	27	2243.2	52	4505.9	77	7151.5
3	249.5	28	2328.5	53	4603.4	78	7256.9
4	332.4	29	2414.1	54	4701.6	79	7383.1
5	415.1	30	2500.0	55	4800.4	80	7500.0
6	497.7	31	2586.3	56	4899.9	81	7617.7
7	580.2	32	2673.0	57	5000.0	82	7736.2
8	662.6	33	2760.0	58	5100.8	83	7855.4
9	745.0	34	2847.5	59	5202.3	84	7975.4
10	827.4	35	2935.4	60	5304.4	85	8096.2
11	909.7	36	3023.7	61	5407.3	86	8217.8
12	992.1	37	3112.4	62	5510.9	87	8340.1
13	1074.5	38	3201.7	63	5615.1	88	8463.2
14	1157.0	39	3291.4	64	5720.1	89	8587.1
15	1239.5	40	3381.5	65	5825.8	90	8711.7
16	1322.2	41	3472.2	66	5932.2	91	8837.1
17	1405.0	42	3563.4	67	6039.3	92	8963.3
18	1487.9	43	3655.1	68	6147.2	93	9090.3
19	1570.9	44	3747.4	69	6255.8	94	9218.0
20	1654.2	45	3840.1	70	6365.1	95	9346.4
21	1737.6	46	3933.5	71	6475.2	96	9475.6
22	1821.3	47	4027.4	72	6586.0	97	9605.6
23	1905.1	48	4121.9	73	6697.6	98	9736.3
24	1989.3	49	4217.0	74	6809.9	99	9867.8
25	2073.6	50	4312.7	75	6923.0	100	10000.0

TABLE A.5. CARBON MONOXIDE (0-11%) CALIBRATION PRINTOUT

Beckman IR Analyzer Calibration Readout for
High Range Carbon Monoxide (0-11%)
Recorder Deflection vs % Concentration

Model No. 315 Amplifier No. 1000351 Detector No. 9962

0-25		26-50		51-75		76-100	
Meter	% CO	Meter	% CO	Meter	% CO	Meter	% CO
0	0						
1	0.08	26	1.69	51	3.96	76	7.00
2	0.16	27	1.76	52	4.07	77	7.13
3	0.23	28	1.83	53	4.18	78	7.27
4	0.31	29	1.91	54	4.30	79	7.41
5	0.38	30	1.98	55	4.41	80	7.54
6	0.44	31	2.06	56	4.52	81	7.69
7	0.51	32	2.14	57	4.64	82	7.83
8	0.57	33	2.22	58	4.76	83	7.97
9	0.64	34	2.30	59	4.87	84	8.12
10	0.70	35	2.39	60	4.99	85	8.27
11	0.76	36	2.48	61	5.11	86	8.42
12	0.82	37	2.56	62	5.23	87	8.58
13	0.88	38	2.65	63	5.35	88	8.74
14	0.94	39	2.74	64	5.47	89	8.90
15	0.99	40	2.84	65	5.59	90	9.07
16	1.05	41	2.93	66	5.72	91	9.24
17	1.11	42	3.03	67	5.84	92	9.41
18	1.17	43	3.13	68	5.97	93	9.59
19	1.23	44	3.23	69	6.09	94	9.78
20	1.30	45	3.33	70	6.22	95	9.96
21	1.36	46	3.43	71	6.35	96	10.16
22	1.42	47	3.53	72	6.47	97	10.36
23	1.49	48	3.64	73	6.60	98	10.57
24	1.55	49	3.75	74	6.73	99	10.79
25	1.62	50	3.85	75	6.87	100	11.00

TABLE A.4. CARBON DIOXIDE (0-15%) CALIBRATION PRINTOUT

Beckman IR Analyzer Calibration Readout for
High Range Carbon Dioxide (0-15%)
Recorder Deflection vs % Concentration

Model No. 315 Amplifier No. 1000851 Detector No. 0961A

0-25		26-50		51-75		76-100	
Meter	% CO_2	Meter	% CO_2	Meter	% CO_2	Meter	% CO_2
0	0						
1	0.07	26	2.48	51	5.24	76	9.37
2	0.14	27	2.38	52	5.38	77	9.57
3	0.21	28	2.49	53	5.52	78	9.77
4	0.27	29	2.60	54	5.66	79	9.98
5	0.35	30	2.71	55	5.80	80	10.19
6	0.42	31	2.81	56	5.95	81	10.40
7	0.50	32	2.92	57	6.09	82	10.62
8	0.58	33	3.04	58	6.24	83	10.84
9	0.66	34	3.15	59	6.39	84	11.06
10	0.74	35	3.26	60	6.54	85	11.29
11	0.83	36	3.37	61	6.70	86	11.52
12	0.92	37	3.49	62	6.86	87	11.75
13	1.01	38	3.61	63	7.02	88	11.98
14	1.10	39	3.72	64	7.19	89	12.22
15	1.19	40	3.84	65	7.35	90	12.46
16	1.28	41	3.96	66	7.52	91	12.70
17	1.38	42	4.08	67	6.69	92	12.95
18	1.47	43	4.21	68	7.87	93	13.20
19	1.57	44	4.33	69	8.05	94	13.45
20	1.67	45	4.46	70	8.23	95	13.70
21	1.77	46	4.58	71	8.41	96	13.96
22	1.87	47	4.71	72	8.60	97	14.22
23	1.97	48	4.84	73	8.78	98	14.48
24	2.07	49	4.97	74	8.98	99	14.74
25	2.17	50	5.11	75	9.17	100	15.00

APPENDIX B

EXHAUST EMISSION CHARTS INDICATING CONTINUOUS ANALYSES OF HYDROCARBONS, CARBON MONOXIDE AND CARBON DIOXIDE

(Note: Original charts furnished only in copy no. 1.)